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Article

Design of the prototype of a system for the quantification of fungal cells

Diseño del prototipo de un sistema para la cuantificación de células fúngicas

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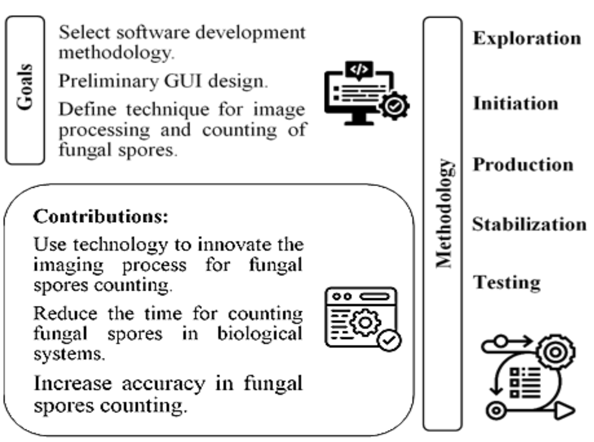
Abstract

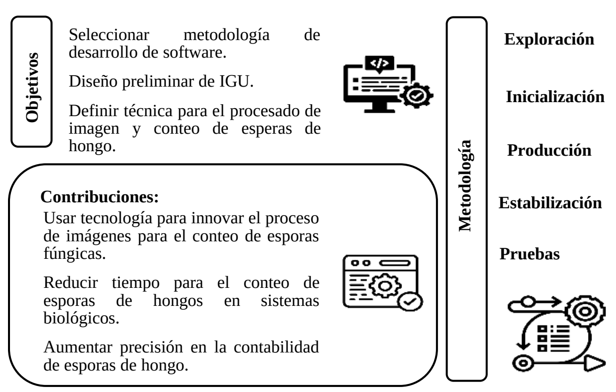
The initial purpose of this research is to design a mobile prototype that, through image processing, counts fungal spores in biological systems. With this, it is sought to make the execution of the process more efficient, as well as its accuracy, because the calculation carried out by the traditional method requires a lot of time and this continues to be not so precise. The Mobile-D methodology will be implemented, which consists of 5 phases: Exploration, Initiation, Production, Stabilization and Testing. This project has the scope of include the design of a prototype, derived from the fact that it is still in a preliminary development stage. In the future, it is intended to develop a mobile application that counts spores through the treatment of images located in a gallery within this tool, allowing you to select one to process it and perform the count that will show the results on the screen, indicating the number and highlighting with an indicative outline each element detected in the image.



Prototype, Spores, Mobile-D

Resumen

Esta investigación tiene como propósito inicial diseñar un prototipo móvil que, mediante el procesamiento de imagen, realice el conteo de esporas de hongos en sistemas biológicos. Con ello, se busca hacer más eficiente la ejecución del proceso, así como su exactitud, debido a que el cómputo realizado por el método tradicional requiere mucho tiempo y este continua sin ser tan preciso. Se implementará la metodología Mobile-D, que consta de 5 fases: Exploración, Iniciación, Producción, Estabilización y Pruebas. Este proyecto tiene como alcance incluir el diseño de un prototipo, derivado de que se encuentra aún en una etapa de desarrollo preliminar. Se pretende desarrollar a futuro una aplicación móvil que contabilice esporas a través del tratamiento de imágenes ubicadas en una galería dentro de esta herramienta, permitiendo seleccionar una para procesarla y realizar el conteo que mostrará los resultados en pantalla, indicando el número y remarcando con un contorno indicativo cada elemento detectado en la imagen.



Prototipo, Esporas, Mobile-D

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Introduction

Fungi were among the first organisms to appear on planet Earth, approximately 300 million years ago. They do not have the ability to form tissues, they are considered ubiquitous because they have the ability or versatility to live in different environments: they can colonise land, water or even air.

The conditions for their development in the environment are based on physico-chemical variables such as humidity, temperature, altitude, light, aeration, pH, nitrogen ions, carbohydrates, etc. Each species will have specific requirements, with independent ecological niches, but the climatic conditions of the tropics favour their development.

Their main function in nature is to degrade dead organisms, therefore they are considered saprophytes. But they can also be symbiotic organisms, living in intimate association with other living organisms for mutual benefit. They are also considered parasites, as they feed on substances produced by other living beings, such as humans, by living in their internal organs or on their surface, and cause damage or disease (Gómez Daza, 2024).

For this work, the first step is the design of a mobile application that allows the versatile and automated counting of fungal spores in the region of the Huasteca Hidalguense. For the moment, in this first step towards the creation of the prototype, only the elements and functions that will integrate the graphical user interface will be defined; in future advances, the operational modules that will allow the use of this tool for its use in the field of research will be developed.

Currently, the procedure for counting fungal spores is performed in the traditional way using a Neubauer chamber. This process has been employed over the years and has been found to require a significant amount of time and effort to perform due to the multiple counts that a laboratorian must perform (Márquez, et al., 2013).

Accuracy depends entirely on the experience of the person examining a sample, as the procedure is done manually, but this can be improved with the use of technology.

This article includes the following sections: Problem, where the situations to be solved with this research are indicated; the justification points out the main purpose of the research where the benefits and impact expected to be generated are indicated; then, the objective to be achieved in this work is included.

The theoretical foundations include the main concepts that relate to and contextualise the reader with the subject of the study; the methodology indicates in an orderly manner the stages in which the research will be carried out; the development shows the work and tasks carried out in each phase of the project's development. The final sections include the results and conclusions of the research, as well as acknowledgements and references.

Problem

Fungal spores are useful for improving various biological processes and systems, as well as preventing their negative effects. This is because some fungi offer great benefits, while others can be detrimental.

In the Huasteca Hidalguense there is a great variety of fungi, both edible and toxic. Some play an important role in the biological systems of the region, including plants, animals and humans, helping to keep them healthy, as long as they are not present in excess or harmful. A study revealed that there are five species of edible mushrooms in the region, identified by their white, purple and yellow colours. In contrast, toxic mushrooms, which are not suitable for consumption, are grey or red in colour (Cipriano, et al., 2019).

This fact is important, because the interaction with these organisms implies the need to know specifically how they expand their colonisation, in order to be used in different activities.

For this purpose, it is necessary to perform spore counting, a procedure that involves collecting a sample of a specific species of fungus. With the sample obtained, the total number of cells present is quantified. Once the number has been determined, their concentration can be assessed and a decision can be made as to whether or not it is beneficial to increase their population.

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This process requires the use of a haemocytometer (an instrument used in medicine and biology to count spores and cells). Once the sample is entered into the instrument, a section is selected for counting. An expert has to count the spores within that section one by one.

From the number obtained, an average of the estimated total of spores in the sample is obtained.

One of the main disadvantages is that counting requires a large amount of time and, by analysing only a part of the total sample, it may not give the most accurate result possible.

Justification

Having detected the need, the aim is to speed up the counting process, resulting as an initial proposal the design of a mobile application that will carry out this task, it will work by entering an image of the spores, so that, through the digital processing of the image, the computation is carried out.

With the help of this tool, the way in which spore counting is carried out would be innovated and speeded up, obtaining more accurate results and reducing the time required to carry out this process.

For the design of this prototype, various techniques will be used that allow for advanced and efficient image processing. Among the most prominent alternatives are **geometric transformations**, including scaling, rotation, transformation and perspective, allowing images to be adapted to different visual contexts. In addition, **image filtering**, particularly non-linear filtering, helps to remove noise without losing important details.

For deeper analysis, **feature detection and extraction** methods can be employed, such as contour detection, which highlights the boundaries of objects within the image. **Image segmentation**, on the other hand, allows the image to be divided into specific regions using models such as watershed, facilitating the identification of relevant areas.

Likewise, **object recognition** using deep learning offers a powerful tool to identify patterns and shapes within the prototype.

In terms of **image morphology**, skeletonisation is useful for simplifying complex shapes, and finally, **image enhancement** by adjusting contrast and brightness optimises the overall visualisation, providing sharper and more defined images. These combined techniques provide a holistic approach to improving the quality and functionality of the prototype. This project aims to generate a great impact by solving the problem detected through digital image analysis, thus giving the possibility to be implemented in other research fields where required, so it is feasible to invest time and/or resources in its development.

Objective

To develop a mobile application that implements artificial vision libraries, advanced image processing techniques and mobile application development environments to reduce the time and effort required to count fungal spores.

Theoretical background

Fungi: Characteristics and importance

Fungi are a group of living organisms devoid of chlorophyll. They resemble simple plants in that, with few exceptions, they have distinct cell walls, are usually non-motile, although they have motile reproductive cells, and reproduce by means of spores (García de la Rosa, 1990).

Like animals, fungi are heterotrophic organisms, which means that they must forage for food in order to survive. Faced with this pressure, throughout their evolution, fungi have developed effective and multiple survival and dispersal strategies, becoming a mega-diverse group whose distribution extends to practically all ecosystems on our planet (Heredia, 2020).

Throughout its history, man has always tried to know living beings in order to differentiate them by their usefulness, harm or to establish systems that allow him to identify them. The use of fungi has different applications, for example, in medicine, where Penicillium is used for the production of penicillin, which is an antibiotic used to fight infections; in the industrial sector, yeasts are used in the production of wine, beer and bread; as food, there are a large number of edible fungi, where mushrooms stand out, as well as other wild mushrooms such as huitlacoche.

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The vast majority of fungi are not harmful to humans, but those capable of producing toxins in food are. The high pathogenicity of fungi is found in vegetables, which are more susceptible to them (Universidad Autónoma de Ciudad Juárez, 2012). In order to study the communities of organisms and ecosystems, several research studies have been carried out. For example, fungi are the most studied organisms due to their role as primary decomposers and their participation in biogeochemical cycles (Cuadros et al., 2011).

Fungi in Mexico

Mexico is a mega-diverse country in terms of groups of organisms, occupying fifth place in the world for its large number of species and endemisms, and has 10% of the planet's terrestrial diversity. As for the diversity of fungi, several investigations have been carried out in order to determine an approximate total of existing fungi. It is estimated that there are around 4,500 species of macro fungi and 2,000 micro fungi in the country, based on bibliographic reviews and specimens from collections. Based on estimation proposals made by different researchers, it is estimated that there are more than 200,000 species of fungi in Mexico, so that the amount currently recorded corresponds to 3.2% of the total number of fungi. (Aguirre, et al., 2014).

Box 1

Figure 1
Huitlacoche, Mexico's representative mushroom
Source: Gobierno de México, 2020

Mushrooms in Hidalgo

The state of Hidalgo has 1,138 species of fungi out of the 4,500 registered nationwide, according to the state diagnosis of biodiversity, prepared by the State Secretariat of Environment and Natural Resources (SEMARNATH), representing 25.3 per cent of Mexico's fungi varieties.

The study detailed that 15.9% of the mushroom species are used in local food, while 6% are used in local medicine, in addition to the fact that before the study began in 2017, there was no accurate data on the diversity of species that inhabit the state (García, 2019).

Mushroom spores

Spores play a crucial role in fungi, just as seeds do in plants. They can be of every conceivable shape: smooth, warty, round, cylindrical, ellipsoid, nabiform, etc. In addition to their shapes, some have other very peculiar characteristics, such as a germinating pore, which can be central, apical, or marginal, larger or smaller. On the other hand, their measurements are unalterable, so that when comparing them with those of the same species they provide us with very reliable data. (Carranza, 2006).

Box

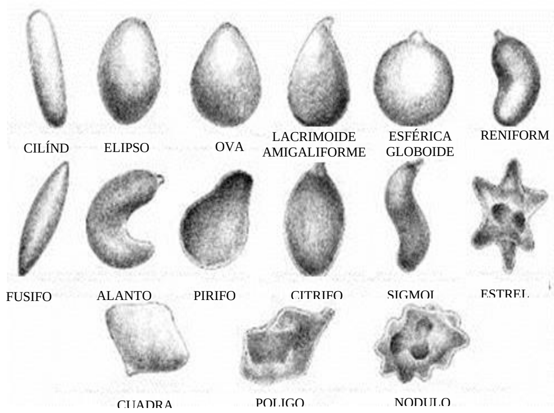

Figure 2
Different forms of spores
Source: Bruns et al., 2002

Spore counting techniques

The Neubauer chamber or haemocytometer, shown in figure 3, is an instrument used for counting fungal spores and biological cells in a liquid medium (distilled water).

Once homogenised, the suspension is filtered through a mesh or gauze to remove agar or mycelial debris that might obstruct the passage of the suspension through the sprayer during inoculation, and brought to a known volume.

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Subsequently, a drop is taken with a Pasteur pipette and placed in the centre of the Neubauer chamber; then the coverslip is placed, taking care that there are no bubbles and that the drop does not spill or fall out of the counting fields; this would give erroneous data, as the excess would drag the spores (Peña Sánchez, et al., 2018).

The chamber consists of two counting fields, each with nine squares, which in turn are divided into smaller squares. Both the large and small squares have known dimensions, so that the number of spores per ml can be obtained by means of formulas. The counting field to be used depends on the size of the conidia of the fungus you are working with. If they are large, it is best to count in the four corner squares (A, B, C, D) plus the centre square (E). In the case of small spore fungi, count the contents of 1, 2, 3, 4 and 5. The count is repeated at least six times and an average is taken (Gilchrist, et al., 2005).

Box

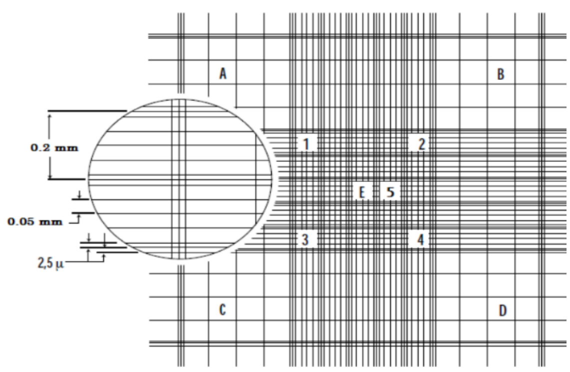

Figure 3
Internal conformation Neubauer chamber

With the data obtained, a mean value is calculated and multiplied by a constant which depends on the chamber used. From this product, the concentration in conidia/ml is obtained. The following formula 1 is used to calculate the counts:

$$Total\ number\ of\ spores = \frac{(NNo.of\ cells\ x\ dilution\ x\ 10^4)}{No.Areas\ mm^2\ counted} \quad (1)$$

This calculation estimates the number/millilitres of suspension. The result is then multiplied by the number of millilitres used in any test for quantification (Bustillo, 2010).

Digital image processing

Digital image processing is an open field of research.

The constant progress in this area is related in conjunction with mathematics, computing, and the increasing knowledge of certain organs of the human body involved in the perception and manipulation of images. The advancement of digital image processing is reflected in medicine, astronomy, geology, microscopy, etc. Meteorological information, transmission and streamlined display of images over the Internet are supported by these advances (Escalante, 2006).

Stages in image processing

The processing stages start from a sequence of image capture and image pre-processing. If the analysis is oriented towards continuous image learning processing (as in the case of a video), for artificial intelligence learning methods, the techniques of focusing and sharpening the capture become more relevant (Kaur, 2016).

In any case, pre-processing is required and the aim of this stage is to reduce 'noise' by scaling an image, and by limiting with upper or lower bounding values the intensity of each pixel in its respective region. Usually blurring and binarisation are applied, but in the case of the need to identify image features, preprocessing is required to find and extract lists of detectors or features, which are regions of pixels with values that fulfil a threshold function and are part of an algorithm that can vary whether high similarity (geometric homography) or close similarity is sought, such as detectors for robust matching. (Montoya, et al., 2014).

Geometric transformations

Geometric transformations are fundamental in image processing and computer graphics, as they allow objects and figures to be modified in various ways.

One of the most common transformations is scaling, which adjusts the size of an object without altering its original shape. This process can be uniform, when the dimensions change proportionally in all directions, or non-uniform, if they change only in some dimensions, such as width or height. In applications such as image resizing or graphic visualisation, scaling is essential to adapt objects to different resolutions and visual contexts (González and Woods, 2018).

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Mathematically, it is represented by scale matrices that multiply the object coordinates by a specific scale factor.

Rotation is another crucial transformation that rotates an object around a fixed point or axis, keeping its size and shape constant. This type of transformation is indispensable in graphics and geometric modelling, as it changes the orientation of objects without altering their internal properties.

In the 2D plane, rotation is performed with respect to a point, such as the origin of the coordinates, while in 3D space, rotation occurs around the X, Y or Z axis (Hartley and Zisserman, 2004).

Rotation is described by angles and is implemented using rotation matrices that adjust the positions of the object's points relative to its centre of rotation.

Geometric transformation, on the other hand, is a more general concept that encompasses several types of modifications that can be applied to an object, such as translation, scaling, rotation and reflection.

These transformations make it possible to change the position, size, orientation or shape of an object in space without changing its fundamental properties. In computer graphics, these transformations are essential to manipulate objects and scenes efficiently, facilitating their representation and analysis (Foley et al., 1995).

Linear transformations, which include combinations of the above, are represented by transformation matrices.

Finally, perspective is a geometric transformation that simulates the projection of a three-dimensional object onto a two-dimensional plane, similar to how human vision or a camera captures images of the real world.

This transformation is fundamental in the creation of realistic graphics and visualisations, as it introduces depth and distance into images.

Through perspective, parallel lines appear to converge at a vanishing point, allowing objects to be represented more accurately, especially in 3D graphics systems (Forsyth and Ponce, 2012).

This perspective projection is key to creating a sense of realism, making distant objects appear smaller and near objects appear larger, replicating the way light enters the human eye or a lens.

Non-linear image filtering

A technique used in image processing to reduce noise without significantly affecting important image features such as edges and fine textures.

Unlike linear filters, which apply a mathematical operation that combines pixel values in a neighbourhood uniformly, non-linear filters evaluate the local structure of the image and adjust pixel values based on specific criteria, such as the order of values in the neighbourhood or the morphology of the analysis area.

One of the best known methods in this field is the median filter, which replaces the value of a pixel by the median of its neighbouring pixel values, effectively removing impulsive noise without blurring the edges (Zhang and Karim, 2002).

Segmentation by regions

The watershed model is often used in images with fuzzy or high-noise edges, as it is able to detect boundaries based on topographic and intensity features, thus avoiding the common problems of gradient-based segmentation techniques. In medical applications, this technique is especially useful for image segmentation in radiology and tomography, allowing the accurate separation of complex anatomical structures, such as organs in MRI studies (Roerdink and Meijster, 2000).

In addition, the watershed algorithm can be combined with other image processing techniques, such as image pre-smoothing or edge detection, to improve results by avoiding over-segmentation, one of the main challenges of this technique when applied without pre-processing. This combined approach has been shown to be effective in areas such as computer vision, biomedical image analysis, and object detection in satellite images and microscopy (González Díaz, et al., 2017).

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Object recognition with deep learning

It is an advanced technique in the field of artificial intelligence and computer vision that allows systems to identify and classify objects within an image or video automatically. Deep learning is based on artificial neural networks that mimic the structure and functioning of the human brain, allowing the system to learn complex patterns and relevant features of images across large datasets (LeCun, et al., 2015).

One of the main advantages of deep learning-based object recognition is its ability to be **autonomous** in feature extraction, eliminating the need to manually design specific descriptors for each type of object, as was done in traditional methods. In addition, it has proven to be robust to noise, distortions and variations in images, making it very efficient in real-world situations where visual conditions are highly variable (He, et al., 2016).

Image morphology

In the field of image processing, the term skeletonisation refers to a morphological analysis technique used to reduce the shape of an object to its fundamental structure or 'skeleton'.

This process is performed by iteratively removing pixels from the edges of a binary object until only the most essential structural components are retained, resulting in a more simplified but topologically equivalent representation of the original object (Kong and Rosenfeld, 1996).

Skeletonisation is especially useful in applications where it is necessary to preserve the structural and topological properties of the object, such as shape analysis, pattern recognition, computer vision and image compression. This technique facilitates the identification of key features of objects in an image, such as their connectivity, symmetry and branch points, which are essential for segmentation and analysis tasks (Lam, et al., 1992).

Image enhancement

Contrast and brightness adjustment is widely used in various fields, including medicine and satellite image processing.

In medical imaging, such as X-rays or MRIs, these adjustments can improve the visualization of internal structures, facilitating the detection of abnormalities or lesions (Khan et al., 2017).

In digital photography and object recognition, contrast adjustment allows for clearer identification of edges and fine details, which is crucial in object classification and segmentation (Pal and Pal, 2011).

Methodology

Mobile-D is a methodology proposed by Pekka Abrahamsson, which has as its main characteristic the rapid development of applications through cycles for small teams (Abrahamsson, 2004).

Box

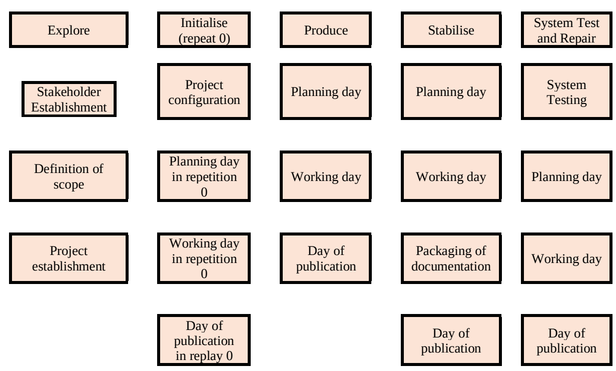

Figure 4
Mobile-D methodology

The exploration focuses on planning attention and basic concepts. The scope of the project and the establishment of functionalities are defined.

The purpose of the initiation phase is to ensure the success of the phases that continue the development of the mobile application by preparing the physical, technical and human resources. Therefore, all preparations are made to realise the project.

The production stage consists of prioritizing the implementation of the customer's requirements by focusing on the basic fundamental operation to allow for multiple improvement cycles. In this phase, the development of the different modules and functionalities of the project begins.

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In stabilization, integration is applied to link the separately developed elements into a single application, whereby the various finished modules are implemented to verify that they work together.

Once the development is fully completed, the testing phase continues until a stable version is achieved according to the client's specifications.

If necessary, bugs are fixed, but nothing new is developed. Feedback on defects and bugs found in the software testing is provided to the development team to be corrected for delivery.

Development

It is important to mention in this section that the initial scope defined for this project will include in this first instance, only the first two stages of the Mobile-D methodology, taking into account that this research will continue with the development and completion of the prototype of a system for the quantification of fungal cells, so only the Exploration and Initialisation phases will be used.

In Exploration stage 1, the problem to be solved was clearly and precisely defined, the initial scope of the project was established, and the preliminary framework was established. This stage included several key activities to ensure that the project is well founded before moving on to more technical phases.

Within the Stakeholder Establishment phase, meetings were held with key stakeholders to address specific objectives such as the initial technical requirements, the potential use of the prototype and possible limitations identified, the people who will interact with the application (experts in the area of Agrobiotechnology), the current issues in fungal cell quantification to determine the functions of the tool and the decisions made regarding the initial scope of the project; all to gain a thorough understanding of the end-users' specifications, and to generate the user requirements document.

The scope of the project focused on defining the development of a prototype to quantify fungal cells using a mobile application.

Here, it was specified that the prototype will perform the computation of fungal spores by using various elements that will help image processing such as geometric transformations (scaling, rotation, transformation and perspective), non-linear image filtering, contour detection, region segmentation using the watershed algorithm, object recognition through deep learning, cell skeletonisation, and brightness and contrast adjustments.

As part of this activity, stakeholder meetings were held to clarify the functional objectives and initial constraints of the project.
Consequently, the testing and validation stages were clearly defined, ensuring that the results will be applicable in various research contexts once completed.

Within the project set-up, a detailed work plan was created, with an initial timeline specifying the team members responsible for each task, with a clear distribution of roles and responsibilities for carrying out the prototype design, and established deadlines and follow-up meetings. The tools and technologies to be used were also identified, such as the development environment for Android applications (Android Studio) and libraries for image processing. In addition, the decision to use this technology was derived from the development of a native Android application, because it offers the advantage of improving the performance of the final application, due to the fact that no adaptation process of the code contemplated in a third-party framework is carried out, as a consequence, the interaction of the tool with the hardware of the devices is carried out directly.

In stage 2, corresponding to Initialisation, the preliminary design of the project was launched, which involves the first sketches of the prototype. The aim of the Initialisation stage is to establish a basic outline of the prototype (version 0) in order to integrate activities that allow the creation of the interface and the functionality of the system. In the configuration phase of the project, the technical and design bases of the mobile prototype were established, because it is essential to define how the graphical user interface (GUI) and interaction flows will be from the beginning to ensure that the end-user experience is intuitive and functional. As a result, sketches were made to capture initial ideas for the user interface.

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These sketches include the layout of key elements of the prototype from the moment the user uploads an image of a sample, until the application performs the quantification of fungal cells.

Box

Figure 5
Welcome screen sketch

In the Planning Day phase in Replay 0, essential tasks were prioritised to build the most basic and functional version of the mobile prototype, paying special attention to the user experience and critical functionalities. In addition, priority screens (such as the image loading screen) were defined.

Within the activities of the Replay 0 Work Day, progress was made in creating the interfaces and connecting the design with the key functionalities of the prototype. The design of the graphical user interface was essential to make the image processing functionalities accessible to the end user. The first screens of the system were implemented, such as the welcome screen, image upload and information screen related to the mobile application

Box

Figure 6
Welcome screen

Finally, a first sample design of the prototype was presented to stakeholders at the Replay Release Day 0 phase. Although this version is an early iteration of the project, it demonstrates the basic functionality of the system and how the interface will allow interaction with the sample images to be counted.

Similarly, feedback was conducted with stakeholders, who provided comments on the design and clarity of functionality.

Box

Figure 7
Prototype design sample

Results

This research has been an outstanding and ambitious initiative that has so far reached several key elements in its development, focusing on the early phases of the Mobile-D methodology, specifically the initialization phase.

During this phase, the team carried out a series of crucial activities that laid the foundations for the technical and methodological development of the prototype. First of all, a precise definition of the functional requirements was established based on the needs of the users.

In addition, a first draft of the graphical user interface design was made, with a focus on usability to facilitate interaction with users who are not specialised in the handling of technical or biological analysis software. The preliminary design of the mobile application included a basic model that will allow the capture and quantification of fungal cells.

In terms of technological resources, the team evaluated and selected the most appropriate hardware and software elements to ensure the optimal future development of this mobile tool.

During the initialization phase, frequent meetings were held with experts in the field of Agrobiotechnology to validate that the defined requirements met the technical requirements necessary for rigorous cell counting. These meetings allowed adjusting some of the functionalities of the prototype, mainly those related to cell detection and quantification, to align them with the expectations of the end users.

On the other hand, some key modules for image data processing are planned to be implemented in the future, although these modules are still in early stages as proposals and require further detailed specifications.

Although these results are preliminary, they indicate that the prototype has the potential to meet the established objectives, although it still needs to be optimized in several aspects, all this, to improve the traditional way of counting fungal spores or biological cells.

Conclusions

The development of this prototype has achieved important milestones in its initialisation phase, particularly in the indication and definition of key requirements and in the preliminary design of the mobile application.

The project has benefited from a collaborative approach, where continuous feedback from experts in the field has been fundamental to adjust and improve the system design, ensuring that it meets the requirements established for this type of application. However, despite this progress, the project is still at an early stage of development, which means that there are still critical areas that need to be addressed in the next phases of the Mobile-D cycle.

Initial feedback from users has shown promising results, but has also highlighted the need for improvements. The project has made significant progress in its initial phase, but there is still a long way to go to reach a fully optimized and highly accurate working prototype.

The development team plans to continue with the development of the remaining stages of the methodology.

It is expected that in the next stages of the Mobile-D cycle, the prototype will be refined and adapted to meet the specific needs of the end-users, allowing for a successful and effective implementation.

The development will continue with a focus on optimization of system performance, integration of new functionalities and thorough validation of the results in real usage contexts.

It can be established that the project has made significant progress in identifying system requirements and creating an initial prototype, although it is still in the early stages of development, with the intention to fully complete its development.

The results obtained so far indicate that the methodological and technical approach is adequate to achieve the proposed objectives.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest. They have no known conflicting financial interests or personal relationships that could have influenced the article reported in this paper.

Authors' contribution

Salazar-Casanova, Hermes: Contributed to the selection of the development methodology to be implemented, design of sketches of the mobile application, research, organization of information, creation of the work plan and writing of this article.

Meneses-Flores, Arturo Elfego: Contributed with the research idea, conducting meetings with stakeholders and defining image processing techniques, meetings to indicate feedback and comments from users.

Mendoza-San Juan, Luis Alberto: Contributed with the specification of requirements, the identification of tools and technologies to be used for the development, as well as the basic construction of the prototype.

Juárez-Castillo, Efrén: Contributed with the identification of tools and technologies to be used for the development, the design of sketches of the mobile application, the basic construction of the prototype.

Availability of data and materials

The information used in this article is available in the publications of the different authors mentioned in the references.

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Abbreviations

IGU	Graphical User Interface
SEMARNATH	Secretaría de Medio Ambiente y Recursos Naturales de Hidalgo
UTHH	Universidad Tecnológica de la Huasteca Hidalguense (Hidalgo's Secretary of Environment and Natural Resources)

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Background

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